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Automated Detection of Retinal Hard Exudates using Triple Circular Segmentation

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Abstract: Many diseases cause harm to the human eye. A diabetic retinopathy could be one of eye disease and it was the essential blindness reason. Diabetic retinopathy earliest marks are the swelling of eye blood vessels that lead to being lesions in the retina. In this research a new algorithm for detecting hard exudates in retina by automated way is proposed. It uses a new algorithm which is based on triple circular segmentation followed by filtering using Kalman filter. Morphological operation is also applied to enhance and to refine the Kalman filter results. The suggested method was tested with 60 images from different databases images and achieved performance was taken with 20 images that obtained sensitivity; 86%, specificity; 99.9%, accuracy; 99.5 % and positive predictive value; 88% which demonstrate the main considerable value of the proposed algorithm. These results are considered a superior performance as compared with the earlier current techniques and are strong to image quality variability.

Key words: Diabetic retinopathy, triple circular segmentation, Kalman filter, retinal imaging, circular segmentation, positive predictive value

INTRODUCTION

Human eyes are the parts that are responsible for the sight sense which is the most important among the 5 human senses. Among the diseases that cause damage in an eye is diabetic retinopathy, it can result in fluid leakage from blood vessels into the retina. To reduce the risk of blindness, it is preferable to take care for an early check to give suitable treatment, hence, early detection and early treatment are very significant. When lesions are present in the central of macular region, the patient can severe from optic loss and the exudates will be performed which make a great damage in the retina. So, monitoring and treating must have done to avoid these risks (Welfer *et al*., 2010). Figure 1 illustrates abnormal retina with its main descriptions and bright lesions.

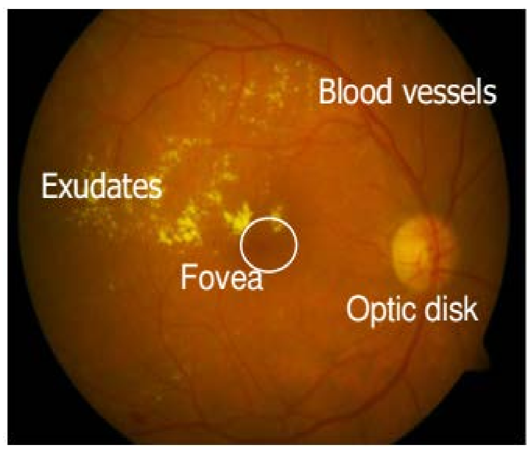

Fig. 1: Retina with the main components for eye and HEs

Retinal lesions for instance Hard Exudates (HEs) are commonly discovered and evaluated manually by an ophthalmologist who is consuming time for diagnosis, and is responsible of testify error. Computer-aided techniques are used to offer help to the clinician for taking correct treatment decision, in addition, it gives a fast and accurate diagnosis of HEs (Jaafar *et al*., 2011). Some techniques were proposed early to detect exudates and suggest a suitable treatment.

There are many methods to identify HEs, one of these techniques is employed to obtain SE of 92% by use morphological reconstruction (Walter *et al*., 2002) while other methods focus on getting the best classification achievement by applying different methods like Artificial Neural Networks (ANN) for classifying segmented regions into exudates and non-exudates (Osareh *et al*., 2002). Another way used to exudates features to classify exudates based on Naive Bayes depending on vector machine classifiers (Sopharak *et al*., 2010), also, the technique that is used to separate exudates from the background is based on comparing models to threshold images but this method has a disadvantage of losing exudates, so, another treatment can give to the patient (Sanchez *et al*., 2009). Fuzzy clustering method was used

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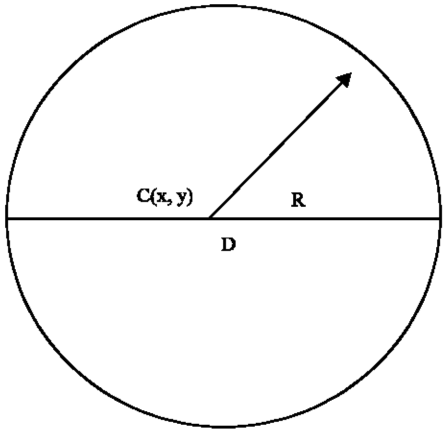

Fig. 2: Circular segment

to segment the color retinal image, next ANN classifier was used for grading regions into exudates and non-exudates (Osareh *et al*., 2003).

In this research, an automatic process is suggested for localizing HEs in color eye image, it depends on a new algorithm system developed here and named as Triple Circular Segmentation (TCS) and has two stages: the first one concentrates on TCS that is used for detection of HEs and second one focuses on Kalman filter to remove noise. This suggested technique doesn't need to understand, in advance, the vessels width and no requirement for removing vessels, all that lead to speed running of the program.

Circular segmentation: Segmentation is the process which is depending on the idea of partition the image into sub images, it is possible to segment image into more shapes and one of them is a circle form (Weinstein, 2018). In geometry, a circular segment is a region of a circle which is "cut off" from the rest of the image. More formally, a circular segment is a region of two-dimensional space that is bounded by a circular boarder as seen in Fig. 2. Equation 1 is taken when a complete shape of the circle is achieved:

$$Y = \sqrt{(x\text{-}C)^2 + (y\text{-}R)^2} \quad (1)$$

where, D is the diameter of the circle, a radius circle is R, C is the value of center and (x, y) is the position of circle center. Image could be segmented into circles, each circle contains number of pixels that values and the positions of centers for each circle in the image is changed depending on the size of the circle. The diameter is growing up or getting smaller depending on the size of object. In addition, there is other types of segments like spherical, conic section and cross section.

After segmentation process, a morphological operation and Kalman filter are applied, so that, morphology is one of the way that employed for segmenting components of the image and is important to describe region shapes such as boundary, skeleton and the convex hull.

Morphological methods are utilized for both pre-processing as well as post-processing, for example, the filling, filtering, prune, thinning and others (Firozl *et al*., 2016). From applications of image-processing dilation and erosion are very important and used in different combinations, series of dilations and erosions operations will apply on the image that using the same or sometimes another structuring element. Dilation and erosion are combined to produce opening and closing operations.

In this research closing and opening techniques were used, such that opening process generally smoothen contour of an image by reducing thin bumps and removing narrow portages. While closing is used to narrow the smooth contours of regions, mix close holes, expand thin gulfs, remove tiny holes, and fill gaps in contours. Morphological opening along with closing are expressed in Eq. 2 and 3 (Gonzalez *et al*., 2009).

$$A^{\circ}B = (A \ominus B) \oplus B \quad (2)$$

$$A \cdot B = (A \oplus B) \ominus B \quad (3)$$

Kalman filter is used in medicinal pictures and it includes information about the active organic tissues for human body and is commonly used to diagnose illness. This algorithm gives better efficiency and high speed, so, it can be a desirable algorithm, due to the vital rule of image reconstruction in medical science. The data can be corrupted due to the noise or in blurring case which causes lost the information during the acquisition process, so, the purpose of the development is to make images with the best contrast and resolution by eliminating noise (Meyer and Beuchar, 1990).

A mathematical method of Kalman filter is relative to the scientist Rudolf E Kalman (Priyanka1 and Kumar, 2016). The method is used to remove noise and other mistakes which tend to be closer to correct values for the results. Many applications of Kalman filter are used in technology, it could be a necessary part of space and military technology development and is commonly employed in image processing while if the proposed system deals with sound analysis then discrete cosine transform or fast Fourier transform may be used to reduce noise (Al-Thahab, 2016).

MATERIALS AND METHODS

Proposed system: The block diagram that offering methods for automated detection of HEs from retinal images is shown in Fig. 3. The proposed TCS with Kalman filter is indicated and the retinal images are used by the program in order to detect the HEs.

Pre-processing: Due to acquisition of image and physical features of eye of the patient, like iris color and skin, almost the images of retina are uneven illuminated. This problem influenced on the process of HEs detection in automatic way and give a difficulty in recognizing HEs from other brighten regions in image of retina. The images of retina are almost non-regular illuminated and sometimes come with low visual contrast. The operations of pre-processing are performed to enhance the image quality and make it better. Usually green component of the color image is taken as input with a selected size of 480*640 pixels and to improve contrast, the Contrast Limited Adaptive Histogram Equalization (CLAHE) is used which is a more frequently used as advanced method than histogram equalization, its effect seen in Fig. 4a. Some image seemed darker and other lighter, so, all images used in this research, must be with even illumination. To enhance image illumination, some regions need to be brighter while others need to be darker. This could be achieved by multiplying the image by specific factor.

The optic disk appears with similar features, of HE and it may be detected wrongly as an exudate, therefore, it is necessary to reduce its influence before starting of detecting HEs. The suggested technique by Sekhar *et al.*, (2008) which is based on computing a center with the radius of optic disk. There are several steps to eliminate or remove OD like: morphological closing applying onto the retinal image that using octagon structuring element of radius 9, then converting it to binary image by Otsu 'threshold then taking morphological closing with disk structure element of raduis10. Canny edge detection is the next step, followed by finding a mask that is overlaid on OD by utilizing circle equation with intensity similar to background intensity (Fig. 4).

Triple circular segmentation: Retinal images are complex image like all medical images, that they may not be segmented by using single threshold. In the beginning the image is partitioned into circular zones, so that, the first level of circular segmentation method covers most region images except HEs which have high pixels' values.

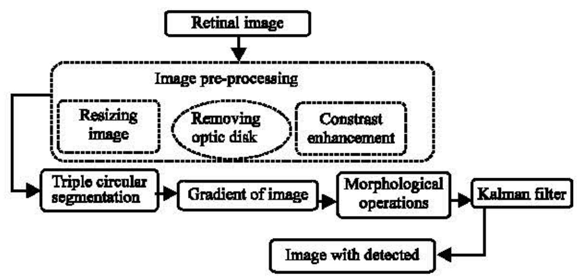

Fig. 3: Block diagram of the proposed method

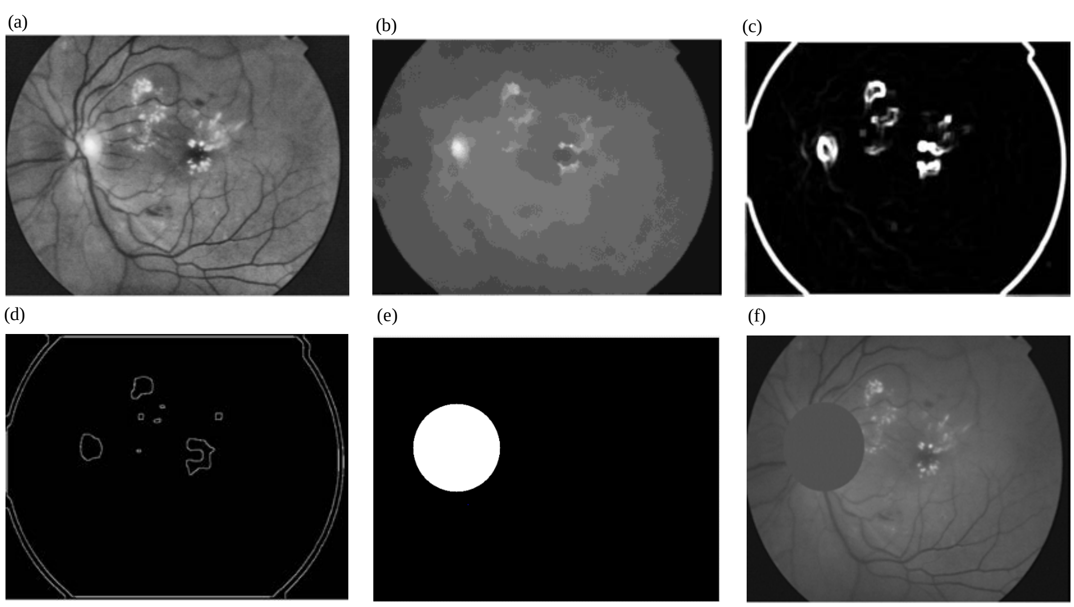

Fig. 4: Preprocessing; a) CLAHE of image; b) Morphological closing; c) Otsu' threshold; e) Canny edge detection; e) Mask for OD and f) Apply mask on retinal image

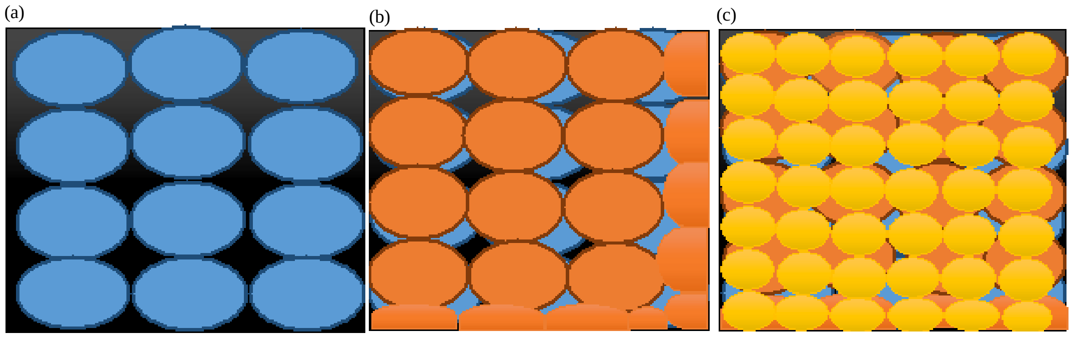

Fig. 5: Circular segmentation; a) First level; b) Second level and c) Third level

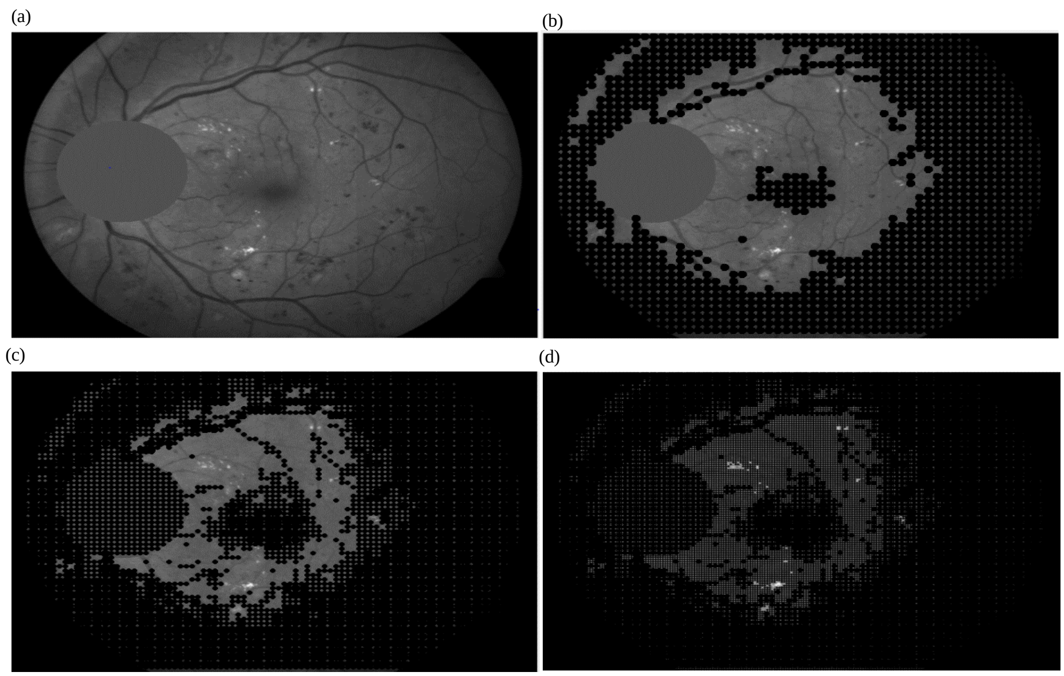

Fig. 6: The circular segmentation levels; a) Primary image; b) First; c) Second and d) Third

Then, second and third level of circular segment action are applied on the image. Each level of segmentation has special threshold and Diameter (D), so that, the diameter decreases in second and third levels such that $D_1>D_2>D_3$, therefore, it is different for every level of segmentation. The circular segmentation was chosen because the shape of HEs is similar to circle shape.

There are three levels used, so, the algorithm is called triple circular segmentation which has an important benefit of removing the gaps between circles. Figure 5 shows the three level of circular segmentations algorithm. While the results for retinal images are in Fig. 6.

Image gradient: The Sobel operator is a discrete differential operator utilized for edge detection also it is used to estimate the gradient of the luminance in the image. In the image gradient, each pixel measures the variety of the intensity of that similar pixel in a given direction in the original image. In (x, y) directions image gradient are computed to get the full range of direction. Like in Eq. 5 (Hafez and Azeem, 2002). Image gradient can be used here to extract information from images and it is created from the original image generally by convolving it with a filter like Sobel filter. The main gradient equation can be shown in Eq. 6 where G_x and G_y are the image in the x-directions and y-direction, respectively, similar to the image source. Figure 7 states the results for the image after the gradient operation:

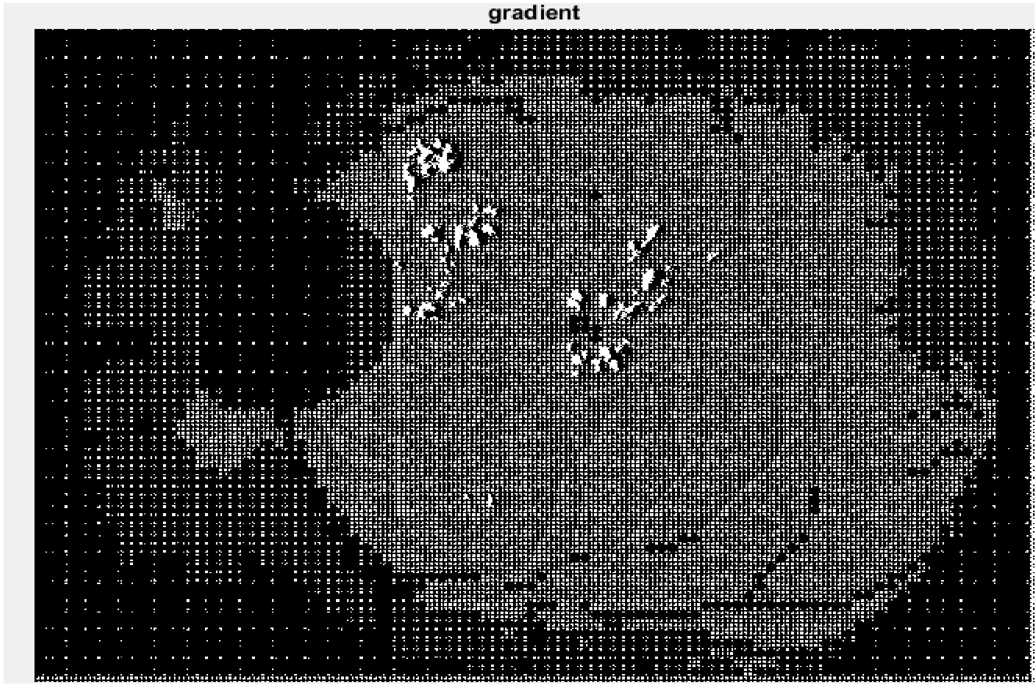

Fig. 7: Image after the gradient operation

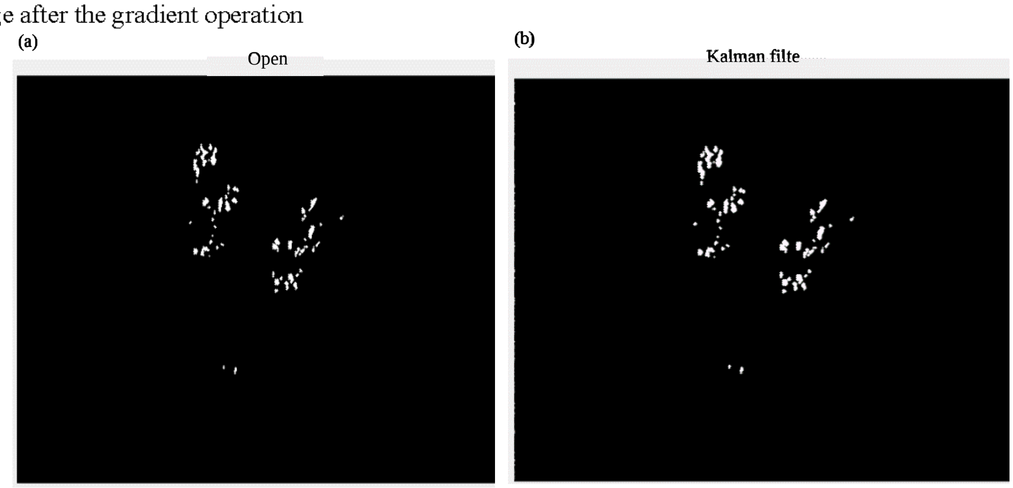

Fig. 8: Result after gradient; a) Opening and b) Kalman filter

$$G_x = \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \quad G_y = \begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \tag{4}$$

Horizontal edge   Vertical edge

$$|G| = \sqrt{G_x + G_y} \tag{5}$$

Morphological operation and Kalman filter: At this stage the morphological opening process is applied here on the result of the image gradient with structuring element of disk-shaped with a fixed radius of 1 pixel, then to reduce noise in the image Kalman filter was employed. It fills some holes of objects found in the image and makes objects appear more clearly in the image. Figurer 8 illustrates the results after the opening and Kalman filter.

RESULTS AND DISCUSSION

The test has been implemented on the abnormal and healthy retinal images for testing and validating the new proposed method. A set of 60 images was used for the test from various databases as follows:

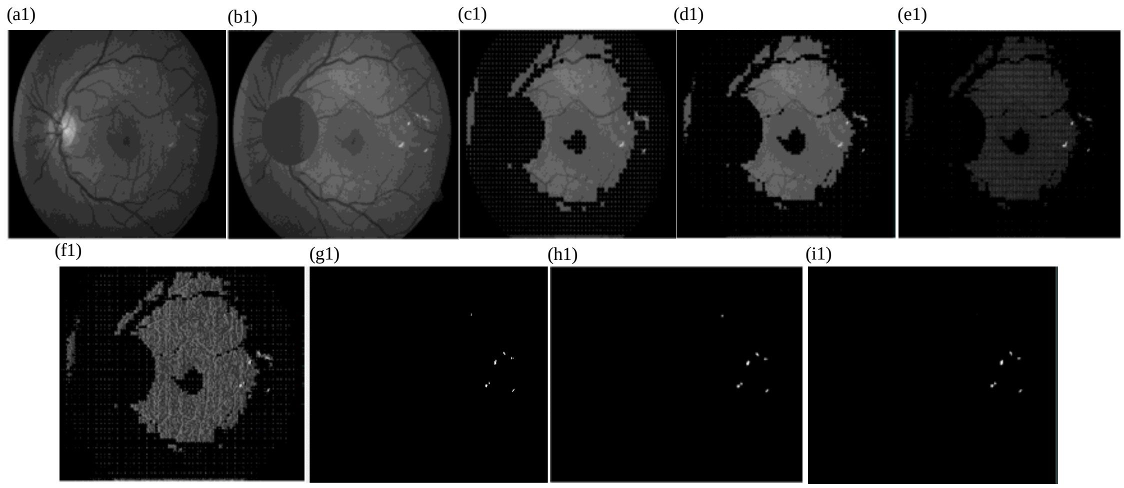

Fig. 9: Left image results; a1) Green image; b1) Result after OD elimination; c1)-e1) First, second and third segmentation; f1) Gradient; g1) Opening and h1) Kalman filter (I1) Ground truth

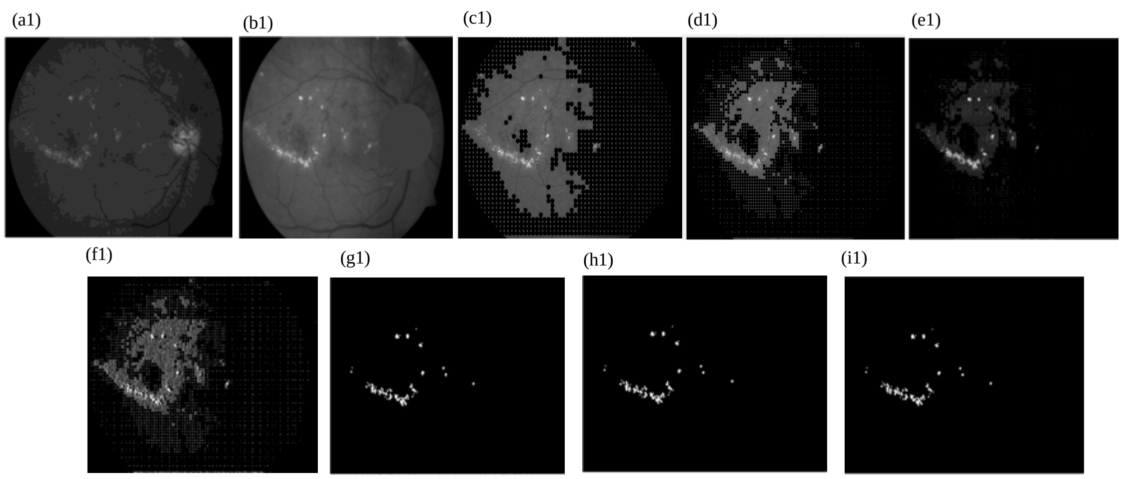

Fig. 10: The right image results; a2) Green image; b2) Result after OD elimination; c2)-e2) First, second and third segmentation; f2) Gradient; g2) Opening; h2) Kalman filter and I2) Ground truth

- From the DIARETDB1 database, 22 images (Kauppi *et al*., 2017) were utilized to satisfy the way at pixel level
- From DIARETDB0 database, 32 images, which is containing unlike signs of DR, fitting to the estimation of ophthalmologists (Kauppi *et al*., 2006). They captured at 50° field of view
- From the messidor database 10 images with HEs and their clinician ground truth images (Walter *et al*., 2002). The suggested method at the pixel level has resolution of 640×480 are utilized in validation

The proposed system performance evaluation is done by making a comparison with clinician hand-labeled images. Here, 20 images are used for validation from different databases. Figure 9 shows the obtained results of the new algorithm for a left image of retina. While Figure 10 shows the obtained results of the method proposed here for a right image of retina. In the evaluation, four kinds of pixels are taken into account: False Negative (FN), True Positive (TP), False Positive (FP) and True Negative (TN). For each individual image, these quantities are computed to calculate the performance by using Eq. 10-13, these equations are applied on all images to obtain the performance of the proposed system:

$$\text{Sensitivity} = \frac{TP_s}{TP_s+FN_s} \quad (6)$$

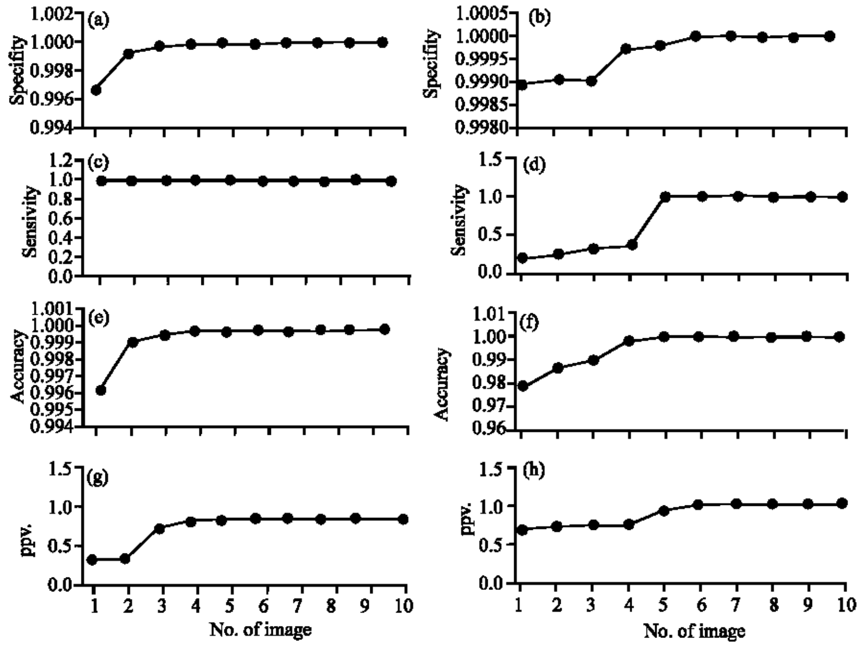

Fig. 11: Performance measurements for left and right images; a) Specifity of left image; b) Specivity of right; c) Sensivity of left image; d) Sensitivity of right image; e) Accuracy of left image; f) Accuracy of right image; g) PPV. of left image and h) PPV. of right image

Table 1: Performance comparison with dissimilar databases

References	Sens. (%)	Spec. (%)	Acc. (%)	PPV	Test
Kande *et al.* (2008)	86	98	92.53	-	47
Welfer *et al.* (2010)	70.48	98.84	-	21.32	47
Osareh *et al.* (2002)	93	82.7	-	-	67
Garcia *et al.* (2009)	88.14	92.6	97	-	67
Sopharak *et al.* (2011)	92.28	98.52	98.41	-	39
Jaafar *et al.* (2011)	93.1	-	-	78.5	106
Proposed method	83.588	99.9	99.5	86.458	20

Sen. is Sensitivity, Spec. is Specificity, Acc. is accuracy

$$\text{Specificity} = \frac{TN_s}{TN_s+FP_s} \quad (7)$$

$$\text{Accuracy} = \frac{TP_s+TN_s}{TP_s+FP_s+TN_s+FN_s} \quad (8)$$

$$\text{Positive predictive value} = \frac{TP_s}{TP_s+FP_s} \quad (9)$$

The proposed method achieves the following performance measures: sensitivity is 83.58%, PPV is 86.45%, specificity is 99.9% and accuracy is 99.5%. In addition, the obtained results of the new method are compared with some close works by using various database as illustrated in Table 1. Here, 20 images are compared with clinician hand-labeled images and obtained good result for PPV, specificity and other measurers.

The curves of the algorithm are shown in Fig. 11. They illustrate a compromise between the number of images that used and parameters of the performance measures which are affected by the threshold, these are tested with right eye images which are different from those of left eye images because of brightness, darkness and position of optic disk for each image.

In this research, hard exudates are auto-detected with a major advantage of greater SP, ACC and PPV. The results are provided from this algorithm with very promising and making auto-detecting of exudates in retinal image accurately.

CONCLUSION

In this research, new automatic hybrid way for the detection of hard exudates is offered. This method can be developed by using Kalman filter combined with the triple circular segmentation algorithm. The research importance grow up from illumination differences of a single retinal image and other different images. There is improvement in performance measures values like the accuracy and specificity, in addition to PPV. In this research, one can observe that it obtained low SE in right eye images and the cause for that was the bad acquisition of images which led to lack in lighting and weak appearance of image features. The obtained results are excellent, so that, TCS is an excellent system than most related works. Here, there is no need for blood vessel extraction and then elimination, because of the use of new TCS algorithm and consequently reducing the processing time and speeds the image analysis. The algorithm was performed with MATLAB 2016 and finally, the algorithm could solve other retinal images problems and for better performance, it is easy to expand and develop.

RECOMMENDATIONS

- The proposed method TCS s could be applicable for detection of red lesions
- For noise removal median filter may be used instead of Kalman filter

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